

Table 5. Mean water depths (instantaneous and crest) at gages for all occasions, during wet and dry seasons (values in feet - sorted by instantaneous depth for all occasions).

Wetland	All Occasions		Wet Season (Oct-Mar)		Dry Season (Apr-Sept)	
	Inst.	Crest	Inst.	Crest	Inst.	Crest
KE	0.17	0.94	0.37	0.93	-	0.95
JC28	0.21	0.52	0.31	0.53	0.14	0.51
SC4	0.28	0.71	0.50	0.69	0.06	0.76
ELS39	0.45	2.09	0.93	2.44	0.08	1.21
AL3	0.49	1.15	0.95	1.15	0.16	-
ELW1	0.53	1.25	0.69	1.57	0.38	0.92
LCR93	0.64	1.39	0.94	1.46	0.19	1.21
LPS9	0.68	2.34	1.08	2.48	0.40	1.94
MGR36	0.73	0.90	0.82	0.97	0.67	0.83
TC13	0.83	1.57	0.83	1.57	-	-
RR5	1.05	1.55	1.31	1.60	0.83	1.49
FC1	1.17	1.90	1.31	2.29	1.06	1.59
SC84	1.19	1.97	1.86	2.46	0.79	1.65
BBC24	1.27	1.71	1.25	1.79	1.29	1.64
ELS61	1.30	1.85	1.52	1.98	1.14	1.70
SR24	1.30	1.88	1.41	1.84	1.22	1.93
PC12	1.73	1.95	1.97	2.15	1.42	1.62
B3I	2.28	2.97	2.41	3.01	2.11	2.86
HC13	2.44	3.08	3.13	3.33	1.22	2.59

Table 6. Maximum water level fluctuation during the wet season, dry season, and for all occasions (values sorted low to high by all occasions data).

	Wet Season (10/1-3/30)	Dry Season (4/1-9/30)	All Occasions
WETLAND	$C_{max}-I_{min}$	$C_{max}-I_{min}$	$C_{max}-I_{min}$
MGR36	0.45	0.54	0.62
SC4	0.39	0.76	0.78
BBC24	0.71	0.70	0.81
JC28	0.81	0.68	0.83
KE	0.98	1.00	1.00
TC13 (a)	1.11	-	1.11
AL3 (a)	0.55	-	1.15
RR5	1.47	1.63	1.63
LCR93	1.22	1.60	1.97
PC12	1.58	1.37	2.00
ELW1	1.88	1.70	2.03
SR24	1.81	2.16	2.25
ELS61	2.02	1.99	2.35
FC1	2.19	1.59	2.40
SC84	0.93	1.99	2.69
B3I	2.57	2.85	2.85
LPS9	3.22	2.64	3.66
ELS39	3.68	1.69	3.68
HC13	2.99	3.88	4.28

(a) No crest readings were available for TC13 and AL3 during the dry season.

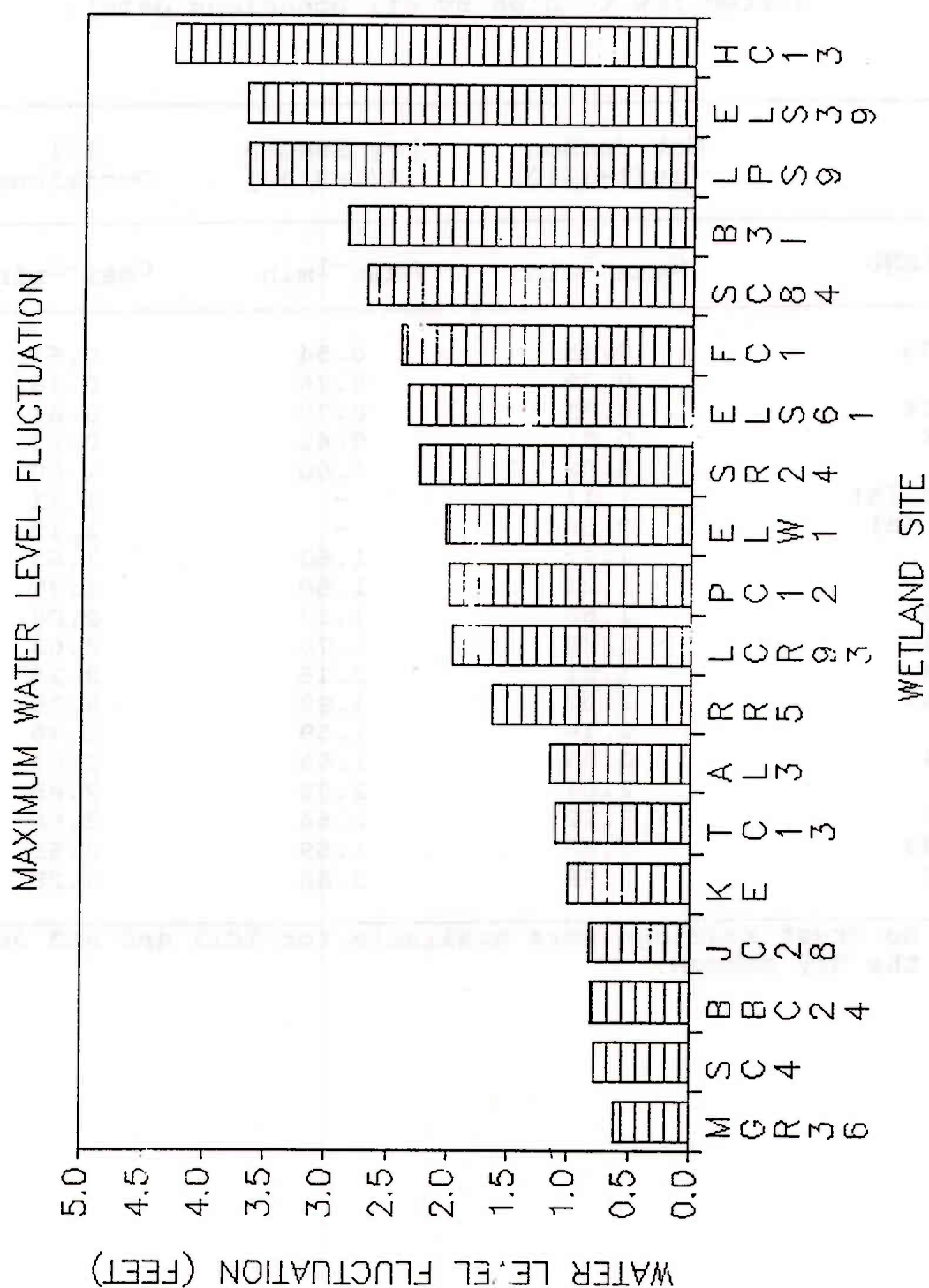


Figure 8. Maximum water level fluctuation for all wetlands from all data

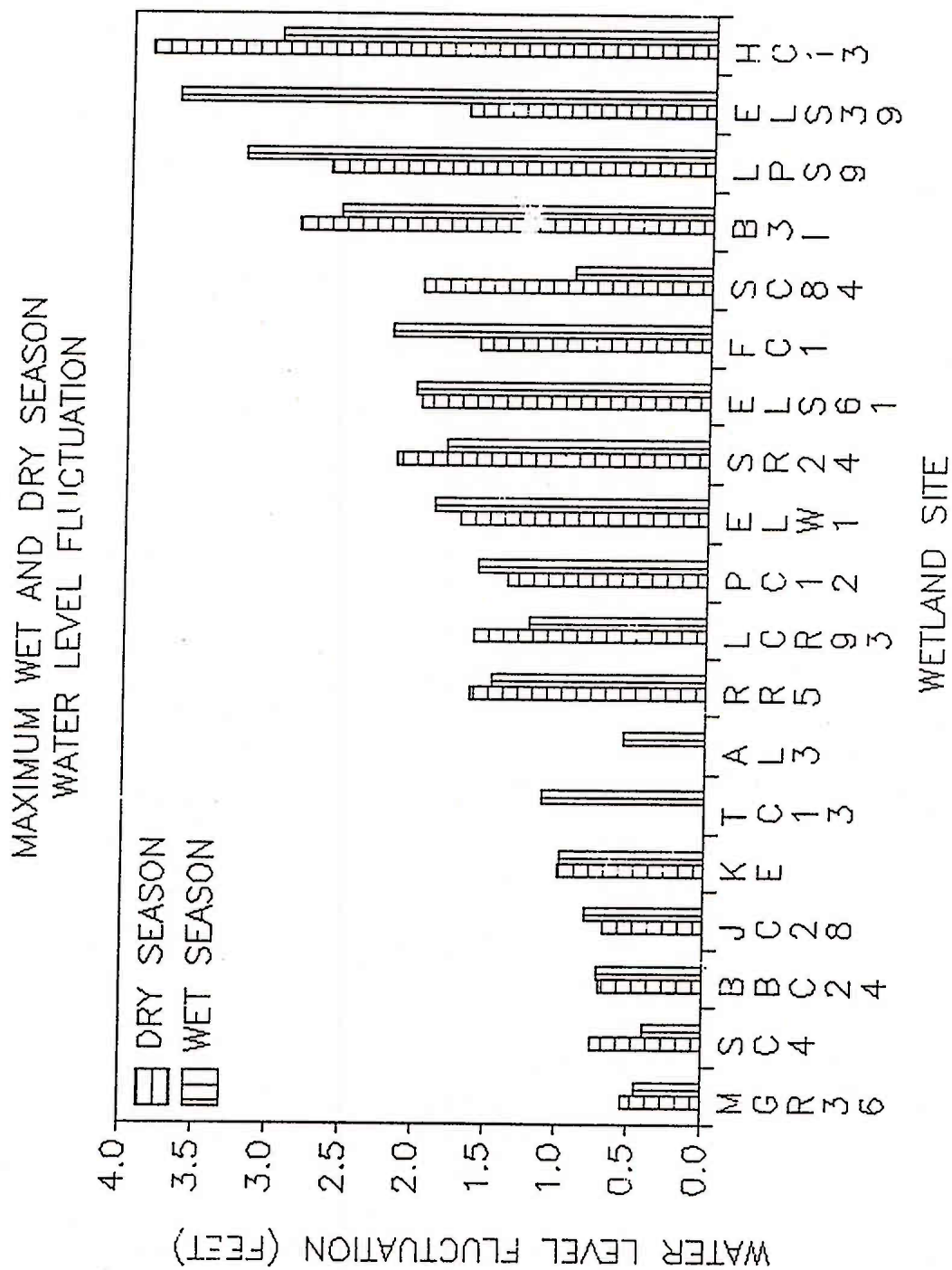


Figure 9. Maximum wet and dry season water level fluctuation

note that minimum instantaneous water depths during the wet season are higher than during the dry season.

Twelve-month precipitation totals for water year 1988 and 1989 (October - September) and calendar year 1988 (January - December) are shown in Table 7 for several precipitation stations around King County. For these two years, between 60 and 75 percent of the precipitation for the 12-month totals fell during the wet season (October - March). Mean 12-month precipitation totals varied from 40.69 to 45.30 inches, with minimum and maximum values of 33.23 and 54.02 inches, respectively. Appendix C2 provides a more detailed summary of the precipitation data.

3.2 Wetland Water Quality

The statistical results for each cell of the water quality data analysis plan shown in Table 3 are presented in Appendix A. In the following sections, the results and discussion reflect a grouping of the water quality data by: (1) wetlands, (2) five categories based on a wetland's treatment status and pre-existing level of watershed development, (3) control versus treatment status, and (4) open-water versus flow-through system. The raw data for the 19 wetlands are shown in Appendix A1.1.

3.2.1 Results by Individual or All Wetlands

Appendix A2.1 contains the seasonal means for all water quality variables for each of the 19 wetlands. Temperature and DO exhibited seasonal trends for all 19 wetlands. Temperatures were lower and DO values were higher during seasons 1 and 5, while temperatures were higher and DO lower during seasons 2, 3, and 4. Alkalinity, pH, and conductivity showed little or no seasonal variation for most wetlands. For some wetlands, however, alkalinity was higher during seasons 2, 3 and 4 than during seasons 1 and 5. For the "bog-like" wetlands (characterized by waters with lower pH, no inlet or outlet and highly organic soils) pH was more variable.

For many wetlands, total suspended solids (TSS) were often significantly higher during one or more seasons than during other seasons. Generally, peak TSS concentrations occurred during seasons 1 or 2 and reflect erosion and transport of sediment from runoff events. For several wetlands, however, peak TSS values occurred during season 3, when algae were probably a significant contributor to the high values.

Mean seasonal chlorophyll *a* values exceeded 10 $\mu\text{g/l}$ in five of the wetlands during season 2 or 3. For these wetlands, open water systems combined with sufficient nutrient inputs to produce algal blooms during the growing season. In many wetlands, ammonia-nitrogen ($\text{NH}_3\text{-N}$), soluble reactive phosphorus (SRP), and total phosphorus (TP) tended to be lower during seasons 1 and 5 and higher during seasons 2, 3 and 4. This may be due in part to

Table 7. Selected 12-month precipitation totals from stations in King County, Washington (Source: King County Surface Water Management)

Station Code	Station Description	Water Year 1988	Calendar Year 1988	Water Year 1989	Water Year 1990
03U	Panther Lake	46.23	49.46	34.27	44.8
14U	Near I-90 and High Point Road	49.79	57.78	53.51	63.0
18U	Redmond Block Development	37.11	42.04	42.88	
25Y	Near 276th Ave SE and Holder Creek	39.36	48.81	54.02	61.7
27U	Fire Station on Kingsgate Hill	45.01	45.52	37.35	40.5
31V	Fairwood Golf Course Clubhouse	33.73	39.95	41.74	43.6
31W	Spring Lake	33.60	33.57	36.18	
32U	East of Auburn Golf Course			37.65	
41U	Star Lake			40.47	
41V	Lake Dolloff			40.71	
46U	Northwest Grand Ridge			48.91	
51U	Norway Hill off 100th Ave NE			34.80	
51W	Near NE 139th Pl. and 162nd Ave NE			33.23	
Mean Precipitation for All Stations		40.69	45.30	41.21	50.7
Mean Precipitation (Oct. - Mar.)		24.45	29.06	30.94	36.7
Percent of 12-month precipitation		60%	64%	75%	72
Mean Precipitation (Apr. - Sep.)		16.24	16.24	10.27	14.0
Percent of 12-month precipitation		40%	36%	25%	20

Water year = October - September; Calendar year = January - December

dilution during higher wet season flows and application of fertilizers during the growth seasons. Nitrate+nitrite-nitrogen ($\text{NO}_3+\text{NO}_2\text{-N}$) was highly variable, but tended to be higher when DO was higher and lower when DO was lower.

The GM for FC and enterococci values were highly variable. Peak GM concentrations for FC occurred most frequently during season 3 and least frequently during seasons 1 and 5. Appendices A2.2 through A2.4 are not presented in Appendix A because the results are virtually the same as for Appendices A5.2 through A5.4.

Appendix A3.1 shows mean values for each wetland for all sampling occasions. There was considerable variability for most of the water quality variables between wetlands. Rather than discuss possible reasons for this variability, or for high/low mean values for individual wetlands, this discussion will follow according to the other groupings of Appendix A3.

Appendix A4.1 shows the various water quality variable mean values using data from all wetlands for each sampling occasion. The 1988 means represent data from between 10 and 14 wetlands (up to four wetlands had no water during one or more occasions during the dry season), while the 1989 means represent data from between 10 and 19 wetlands (up to nine wetlands had no water during one or more occasions). Most of the mean values for the water quality variables appear to exhibit occasion or seasonal variation. It is difficult to distinguish this variability with certainty, though, since the number of wetlands sampled changed with the seasons and the new additions in 1989. Chlorophyll a, phaeophytin a, TSS and $\text{NH}_3\text{-N}$ showed the greatest variation for the 15 occasions. More sophisticated statistical analyses will be performed in the future to investigate these occasion trends.

Appendix A5.1 contains summary statistics for all wetlands by the five seasons (Section 2.2). Most of the water quality variables exhibited seasonal variation; however, temperature, chlorophyll a, $\text{NH}_3\text{-N}$, SRP, TP, FC and enterococci exhibited greater variation. More detailed discussions of the seasonal variation for the different water quality variables follow in Appendices A5.2 through A5.4.

3.2.2 Results by Treatment Status and Pre-existing Level of Watershed Development

Appendix A3.2 shows mean values for each of five categories of wetlands based on treatment status and pre-existing levels of watershed development (Section 2.2). The CH wetland mean values were highest among the five categories for temperature, DO, pH, conductivity, alkalinity and TSS; FC and enterococci GM values were also relatively high. The CH values were lowest for total organic carbon (TOC). The GM of FC values for the CH wetlands was 275 organisms/100mL (org/100mL). This exceeds the water

quality criteria for surface waters of Washington State for Class AA, A, and B waters (50, 100, and 200 org/100mL., respectively). It is important to note, however, that wetlands are not classified as surface waters when considering these criteria.

The TM wetland mean values were second highest for the same variables as CH (except temperature) and highest for chl a and NO₃+NO₂-N. Conductivity, alkalinity, TSS, and FC mean or GM values exhibited the greatest differences between the wetlands with the higher level of watershed development (CH and TM), as compared with the other three categories (CN, CM and TN).

Appendix A4.2 contains summary statistics for each of the five categories by sampling occasion. From these data it is possible to separate out treatment status and pre-existing watershed development differences by occasion. Many of the differences indicated above in the discussion about Appendix A3.2 are similar. The CH wetland mean values were highest on most occasions for pH, conductivity, alkalinity, FC and enterococci, and lowest for TOC. The TM wetland mean values were usually second highest or highest for conductivity, alkalinity, TSS, chlorophyll a, TP, FC and enterococci.

Appendix A5.2 shows mean values for each of the five categories by the five seasons (Section 2.2). In this appendix it is possible to distinguish seasonal differences among the five categories. Again, the CH wetland mean values are highest during most seasons for DO, pH, conductivity, alkalinity, FC and enterococci, and lowest for TOC. Similarly, the TM wetland mean values are second highest or highest during most seasons for conductivity, alkalinity, TSS, chlorophyll a, TP, FC and enterococci.

The results of the water quality analysis for the five categories (CN, CM, CH, TN and TM) clearly shows the effects of urbanization on several water quality variables in wetlands. In particular, conductivity, alkalinity, TSS, TP, FC and enterococci all seem to be highest in those wetlands with significant or increasing development in their watersheds. The above analyses show that it is possible to identify changes in wetland water quality as a result of increasing urbanization, however, it is much more complex to assess the impact of degraded water quality conditions on wetland ecosystem functioning. This will be the focus of future efforts when the water quality data is combined with data on hydrology, soils, plants and animals.

3.2.3 Results by Treatment Status

Appendices A3.3, A4.3, and A5.3 show summary statistics for the wetlands based on their control or treatment status. There have been varying levels of new development in the watersheds of the treatment wetlands. Some developments are complete, some are beginning or will begin soon, and others are in an intermediate

stage of development. Two control wetlands (B3I and FC1) that have highly urbanized watersheds were not included in this analysis.

Appendix A3.3 contains summary statistics for control and treatment wetlands for all occasions. When examined cumulatively (i.e., for all occasions), the nine control wetlands and eight treatment wetlands exhibited no significant differences based on the Student's t-test. The t-statistic at the 0.05 significance level (d.f. = 15) is 1.753. All of the t-statistics for the various water quality variables were below 1.753, indicating that there is insufficient evidence to indicate a difference between treatment and control wetlands.

Appendix A4.3 contains summary statistics for control and treatment wetlands for each of the 15 sampling occasions. Again, the t statistic was used to compare control and treatment wetlands for each occasion. SRP was significantly higher in the treatment wetlands on six of the 15 occasions. No other variables exhibited significant differences between control and treatment wetlands on more than three occasions.

Appendix A5.3 contains summary statistics for control and treatment wetlands for each of the five seasons (Section 2.2). Conductivity was significantly higher in the treatment wetlands during four of the five seasons (season 4 was the exception) and $\text{NO}_3+\text{NO}_2\text{-N}$ was higher during seasons 2, 3 and 5. No other variables exhibited significant differences for more than one season.

From the above analyses, SRP, conductivity and $\text{NO}_3+\text{NO}_2\text{-N}$ were the only water quality variables that emerged as significantly higher in the treatment wetlands. All three often increase as a result of watershed development and reflect higher loadings of nutrients and dissolved salts. Several studies have shown increased concentrations of these variables as a result of watershed development (Reckhow et al. 1980; Welch et al. 1985; Horner et al. 1987; Walker 1987; Wulliman et al. 1989).

Though some water quality variables emerged as potentially significant indicators of treatment wetlands, overall there were relatively few differences between control and treatment wetlands during the first two years of the study. This could be due to a number of factors, including: (1) timing, extent, and proximity of the development(s), (2) pre-existing watershed conditions, (3) wetland to watershed ratios, (4) type of wetland systems, and (5) topography. These and other factors will be considered in future analyses to determine whether certain factors are confounding the analysis of control versus treatment wetlands.

3.2.4 Results by Hydrologic System

Appendices A3.4, A4.4, and A5.4 show summary statistics for the wetlands based on their hydrologic conditions (i.e., open-water system versus flow-through system). This analysis was carried out to determine if there were differences between water quality variables due to factors such as light exposure, water exchange and residence time. Again, the Student's t-test was used to compare the two means.

Appendix A3.4 contains summary statistics for open-water and flow-through wetlands for all occasions. The t-statistic at the 0.05 significance level (d.f. = 17) was 1.74. Conductivity, pH, alkalinity, phaeophytin a, $\text{NO}_3+\text{NO}_2\text{-N}$, FC and enterococci were significantly different between open-water and flow-through systems. The lower values for pH and alkalinity in the open-water systems reflected partly the three "bog-like" wetlands included in this category. Conductivity was much higher in the flow-through systems because of the high level of urbanization in the watersheds of several wetlands in the flow-through category.

Chlorophyll a (significant at the 0.10) and phaeophytin a, indicators of algal growth, were higher in the open-water systems due to greater light exposure and longer residence times. The higher $\text{NO}_3+\text{NO}_2\text{-N}$ values in the flow-through systems occurred probably as a result of higher DO levels. Higher bacteria levels in the flow-through systems likely resulted from the greater urbanization of those wetland watersheds and the quiescent nature of open-water systems, which allows sediment particles and associated bacteria to settle out.

Appendix A4.4 contains summary statistics for open-water and flow-through system for each of the 15 sampling occasions. Conductivity was significantly higher in the flow-through wetlands on all 15 occasions, alkalinity was higher on 14 occasions and pH was higher on 11 occasions. As noted above, these conditions occurred, probably, as a result of the high level of urbanization in several flow-through wetlands and the "bog-like" characteristics of several wetlands in the open-water category. Temperatures in the open-water systems were significantly higher on nine occasions, primarily from May to October.

$\text{NO}_3+\text{NO}_2\text{-N}$ concentrations were higher in the flow-through systems on 11 of 15 occasions. FC and enterococci were higher on 12 and 11 occasions, respectively. This confirms the above findings for the "all occasions" data. Chlorophyll a was significantly higher and DO lower in the open-water systems on four of 15 occasions. On several other occasions during the growth season chlorophyll a values were much higher in the open-water systems, but the high variance of the values led to a nonsignificant difference.

Appendix A5.4 contains summary statistics for open-water and flow-through systems for each of the five seasons. Conductivity, pH and alkalinity were significantly higher in the flow-through wetlands during all five seasons. $\text{NO}_3+\text{NO}_2\text{-N}$ and enterococci also were higher in the flow-through wetlands during four of five seasons. DO was higher in the flow-through wetlands and chlorophyll a was higher in the open-water wetlands during three of five seasons. These conditions mirror the results shown in Appendices A3.4 and A4.4.

Temperature, DO, and chlorophyll a were expected to exhibit the main differences between open-water and flow-through systems. Temperature and chlorophyll a were expected to be significantly higher in the open-water wetlands during the late spring to early fall period when light exposure is greatest and there is less water exchange. DO was expected to be higher in flow-through wetlands because of greater flow turbulence and reoxygenation, and less oxygen consumption from decomposition of organic materials.

Conductivity, pH, alkalinity, FC and enterococci were not expected to show significant differences. As noted above, the differences in conductivity, pH, and alkalinity likely resulted from differences in wetland types and watershed conditions, not differences in the hydrologic systems. FC, enterococci and $\text{NO}_3+\text{NO}_2\text{-N}$ may be related to the hydrologic system. As noted above, higher bacteria levels in the flow-through systems likely resulted from the greater urbanization of those wetland watersheds and the quiescent nature of open-water systems, which allows sediment particles and associated bacteria to settle out.

$\text{NO}_3+\text{NO}_2\text{-N}$ was higher in the flow-through systems, perhaps because of the higher DO levels in the flowing waters. Many of the differences between open-water and flow-through systems will be further explored in the future by more detailed statistical analyses.

3.2.5 Total and Dissolved Metal Concentrations in Wetlands

In 1988, water samples were analyzed for total and dissolved cadmium (Cd), copper (Cu), lead (Pb) and zinc (Zn) on four occasions. A total of 49 samples was analyzed. The detection limits for Cd, Cu, Pb, and Zn were 0.5, 5, 5, and 20 $\mu\text{g/L}$, respectively. Detectable levels of dissolved Zn and Cu occurred in only two samples (4 percent) and one sample (2 percent), respectively. All samples were below detectable levels for dissolved Cd and Pb. For total metals, the number of detectable samples and their associated percentages for Cd, Cu, Pb, and Zn were one (2 percent), five (10 percent), nine (18 percent) and five (10 percent), respectively. Thus, only 23 of 392 analyses (6 percent) had metal concentrations above detectable levels.

In 1988, wetlands B3I, JC28 and LPS9 had, respectively, five, three and three of the 20 total metal concentrations above detectable levels (Table 8). Wetlands LCR93, ELS61 and SR24 had two samples above detectable levels. No other wetlands had more than one sample above detectable levels.

Because of the results obtained in 1988, the frequency of metals sampling was reduced to three occasions and dissolved metals were dropped from the analysis in 1989. At the start of 1989, there was also a reduction in the detection limit for Zn from 20 to 8 $\mu\text{g/L}$. In 1989, metals sampling occurred during March, May and November. Of the 76 samples (4 x 19 wetlands) analyzed during March, only four samples (5 percent) contained concentrations above detectable levels (Cd = 1, Pb = 2 and Zn = 1) (Table 8). In May and November, however, there was a significantly different picture.

In May, 29 of the 76 samples (38 percent) contained metals above detectable levels (Cd = 3, Cu = 7, Pb = 5 and Zn = 14). In November, 27 of the 76 samples (36 percent) contained metals above detectable levels (Cu = 7, Pb = 1 and Zn = 19). Only four of the 14 samples for May and nine of the 19 samples for November would have been detected using the old Zn detection limits. The range of detected metals for May and November was:

Cd: 0.6 - 0.8 $\mu\text{g/L}$
Cu: 5 - 15 $\mu\text{g/L}$
Pb: 6 - 22 $\mu\text{g/L}$
Zn: 8 - 49 $\mu\text{g/L}$

Table 8 shows all total metal concentrations for 1988 and 1989 that were above detectable levels. In addition, summary statistics show the mean, SD, CV, minimum and maximum of these values.

It is possible that fewer metals were detected during the March sampling occasion because of greater dilution resulting from higher runoff volumes. A similar response was expected for the November sampling occasion; however, this did not occur. Future analyses examining the relationship between precipitation events, hydrologic season and metals concentrations will be explored to illuminate these differences. Further discussion of the metals data with respect to criteria follows in Section 3.2.6.

3.2.6 Criteria for Water Quality Data

Water quality data are often compared with criteria for purposes of assessing the conditions of the waters in question. Criteria may take the form of regulatory standards or generally accepted values derived from research literature. For purposes of comparison in the following analysis, informal criteria also were established based on the author's experience and judgment, and how the data were grouped.

Table 8. Results of metal analyses for all wetlands (sorted by wetland and date) (a)

Date mm/dd/yy	Wetland Name	Tot Cd (µg/L)	Tot Cu (µg/L)	Tot Pb (µg/L)	Tot Zn (µg/L)	
05/23/89	AL3	0.8	15	14	31	
11/16/89	AL3	-	9	-	49	
07/12/88	B3I	-	-	10	30	
09/06/88	B3I	-	-	-	21	
10/05/88	B3I	-	-	-	38	
11/30/88	B3I	-	-	6	-	
03/27/89	B3I	-	-	-	19	
05/24/89	B3I	-	-	-	21	
11/16/89	B3I	-	-	-	37	
05/23/89	BBC24	-	-	-	8	
11/16/89	BBC24	-	-	-	13	
11/14/89	ELS39	-	-	-	18	
09/06/88	ELS61	-	-	6	-	
11/28/88	ELS61	-	6	-	-	
05/23/89	ELS61	-	6	5	8	
11/14/89	ELS61	-	11	-	23	
05/23/89	ELW1	-	-	6	24	
11/16/89	ELW1	-	-	-	10	
05/23/89	FC1	-	6	-	12	
11/16/89	FC1	-	7	-	14	
10/05/88	HC13	-	10	-	-	
11/16/89	HC13	-	-	-	11	
07/11/88	JC28	-	5	6	-	
10/03/88	JC28	-	-	-	120	
03/27/89	JC28	-	-	8	-	
11/14/89	JC28	-	-	-	20	
03/28/89	KE	4.0	-	-	-	
05/24/89	KE	-	-	-	16	
11/14/89	KE	-	-	-	22	
07/11/88	LCR93	-	-	21	-	
11/28/88	LCR93	-	8	-	-	
11/14/89	LCR93	-	-	-	30	

incl. 14

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Table 8. Continued

Date mm/dd/yy	Wetland Name	Tot Cd ($\mu\text{g/L}$)	Tot Cu ($\mu\text{g/L}$)	Tot Pb ($\mu\text{g/L}$)	Tot Zn ($\mu\text{g/L}$)
07/11/88	LPS9	-	-	9	-
10/03/88	LPS9	-	8	12	-
05/24/89	LPS9	0.7	12	22	30
11/14/89	LPS9	-	7	-	23
09/06/88	MGR36	-	-	7	-
11/14/89	MGR36	-	-	-	10
07/11/88	PC12	-	-	-	20
11/16/89	PC12	-	-	-	16
09/06/88	RR5	0.7	-	-	-
05/24/89	RR5	-	-	-	18
11/14/89	RR5	-	-	-	20
03/27/89	SC4	-	-	8	-
05/24/89	SC4	-	7	11	15
11/14/89	SC4	-	5	-	19
05/24/89	SC84	0.6	7	-	9
11/14/89	SC84	-	5	8	14
07/12/88	SR24	-	-	5	-
09/07/88	SR24	-	-	5	-
05/23/89	SR24	-	-	-	11
11/16/89	SR24	-	-	-	12
05/23/89	TC13	-	6	-	18
11/16/89	TC13	-	5	-	31
Mean		1.4	7.6	9.4	22.7
SD (b)		1.3	2.6	4.9	18.4
CV (c)		0.97	0.35	0.53	0.81
Minimum		0.6	5	5	8
Maximum		4.0	15	22	120

(a) values shown for all analyses with metal concentrations above detectable levels; detectable levels: Cd = 0.5 $\mu\text{g/L}$, Cu & Pb = 5 $\mu\text{g/L}$, Zn = 20 $\mu\text{g/L}$ in 1988, 8 $\mu\text{g/L}$ in 1989; - indicates value below detectable levels

(b) SD = Standard Deviation

(c) CV = Coefficient of Variation = SD/Mean

The criteria used for comparison with the wetland water quality data (Table 9) were developed from the following sources. "Water Quality Standards for Surface Waters of the State of Washington" (Chapter 173-201 WAC) established standards for FC, DO, temperature and pH. The FC standards for Class AA, A, and B waters were used directly, but criteria for temperature (10°C), pH (7) and DO (6 mg/L) were established based on data groupings and recommended DO levels for salmonids. "Quality Criteria for Water 1986" (EPA 1986) established criteria for alkalinity (20 mg/L or more as CaCO₃), enterococci (33 org/100mL), and metals based on a hardness of 50 and 100 mg/L as CaCO₃, respectively: Cd (0.66 and 1.1 µg/L), Cu (6.5 and 12 µg/L), Pb (1.3 and 3.2 µg/L) and Zn (59 and 110 µg/L). These metal criteria represent four-day average concentrations. Hardness was not measured in this study, but values of 50 and 100 mg/L as CaCO₃ were selected based on alkalinity and used as indices for comparing measurements with some standard.

Criteria for winter TP (20 and 50 µg/L) and summer chlorophyll a (10 µg/L) were obtained from research literature as summarized by Welch (1980). Criteria for conductivity (100 and 200 µmhos/cm), TSS (5 and 10 mg/L), NO₃+NO₂-N (500 µg/L), NH₃-N (50 and 100 µg/L), and SRP (20 µg/L) were established based on the authors' judgment and grouping of the data. It is important to note that nearly all of the above criteria were established for freshwater lakes and streams, and therefore may not be directly applicable to wetlands. For illustrative and comparison purposes, however, these values are used in the following discussion.

In Table 9, mean values from all occasions for each of the 19 wetlands were compared with the criteria. These comparisons are made for all wetlands and by the different categories discussed in Sections 3.2.2 through 3.2.4. The range and CV are also shown for each variable based on Appendix A3.1. Selected variables with well-established criteria or of particular interest because of associated impacts are examined below for the 19 wetlands.

Mean DO values in nine of the 19 wetlands were below 6 mg/L and therefore would not offer good support to salmonid species. Generally, the open-water wetlands had lower DO values. Salmonids have been observed in two of the flow-through wetlands (B3I and FC1). Mean TSS values above 10 mg/L occurred in three of the wetlands during 1988 and 1989. The highest mean value (15.9 mg/L) occurred in wetland ELS61, where significant erosion from the construction of a large church and single-family homes in the watershed has produced heavy sediment loadings to the wetland. The B3I and LPS9 wetlands, receiving runoff from highly and moderately urbanized watersheds, respectively, had mean values of 11.7 and 14.0 mg/L, respectively.

Summer mean chlorophyll a values exceeded 10 µg/L in seven wetlands. Five of the seven were treatment wetlands and five of

Table 9. Criteria Comparison for Variables from All Occasions at Each Wetland (a)

Variable	CV (b)	Range	Criteria	CN	CM	CH	TN	TM	C	T	All	OW	FT
Temp. (degrees C)	0.25	6.2-12.9	<10	2	3	0	2	3	5	5	10	5	5
			>10	3	1	2	1	2	6	3	9	6	3
DO (mg/l)	0.37	1.6-8.3	<6	3	2	0	2	2	5	4	9	7	2
			>6	2	2	2	1	3	6	4	10	4	6
pH (-log[H ⁺])	0.08	5.4-7.3	<7	4	4	0	3	4	8	7	15	11	2
			>7	1	0	2	0	1	3	1	4	0	4
Cond. (μmhos/cm)	0.57	25-218	<100	4	3	0	3	1	7	4	11	9	2
			100-200	1	1	0	0	3	2	3	5	2	3
			>200	0	0	2	0	1	2	1	3	0	3
Alk. (mg/l CaCO ₃)	0.91	0.9-83	<20	4	2	0	2	1	6	3	9	7	2
			20-50	0	2	0	1	3	2	4	6	4	2
			>50	1	0	2	0	1	3	1	4	0	4
TSS (mg/l)	0.71	1.8-15.9	<5	3	3	0	3	1	6	4	10	7	3
			5-10	2	0	1	0	3	3	3	6	3	3
			>10	0	1	1	0	1	2	1	3	1	2
Chl a (μg/l) (c)	1.59	0.8-38	<10	4	3	2	1	2	9	3	12	6	6
			>10	1	1	0	2	3	2	5	7	5	2
NH ₃ -N (μg/l)	1.10	12-495	<50	2	1	1	2	1	4	3	7	5	2
			50-100	2	2	1	1	2	5	3	8	4	4
			>100	1	1	0	0	2	2	2	4	2	2
NO ₃ -N (μg/l)	0.84	50-1506	<500	4	2	1	3	2	7	5	12	10	2
			>500	1	2	1	0	3	4	3	7	1	6
TP (μg/l) (d)	0.94	21-335	<20	1	2	0	0	0	3	0	3	2	1
			20-50	3	0	0	2	3	3	5	8	6	2
			>50	1	2	2	1	2	5	3	8	3	5
Fecal Col. (#/100ml)	0.60	1-328	<50	4	4	0	3	4	8	7	15	11	4
			50-100	0	0	0	0	0	0	0	0	0	0
			100-200	1	0	0	0	0	1	0	1	0	1
			>200	0	0	2	0	1	2	1	3	0	3
Enteroc. (#/100ml)	0.36	4-241	<33	3	3	0	3	3	6	6	12	10	2
			>33	2	1	2	0	2	5	2	7	1	6

Table 9. Continued

Variable	CV	Range	Criteria	CN	CM	CH	TN	TM	C	T	All	OW	FT
Total Cadmium ($\mu\text{g/l}$)	0.97	0.6-4											
(e)			<1.1	5	4	2	2	5	11	7	18	10	8
			>1.1	0	0	0	1	0	0	1	1	1	0
(f)			<0.66	3	3	2	2	5	8	7	15	8	7
			>0.66	2	1	0	1	0	3	1	4	3	1
Total Copper ($\mu\text{g/l}$)	0.35	5-15											
(e)			<12	4	3	2	3	5	9	8	17	10	7
			>12	1	1	0	0	0	2	0	2	1	1
(f)			<6.5	3	1	1	3	3	5	6	11	7	4
			>6.5	2	3	1	0	2	6	2	8	4	4
Total Lead ($\mu\text{g/l}$)	0.53	5-22											
(e)			<3.2	2	1	1	3	1	4	4	8	8	1
			>3.2	3	3	1	0	4	7	4	11	4	7
(f)			<1.3	2	1	1	3	1	4	4	8	8	1
			>1.3	3	3	1	0	4	7	4	11	4	7
Total Zinc ($\mu\text{g/l}$)	0.81	8-120											
(e)			<110	5	4	2	3	4	11	7	18	11	7
			>110	0	0	0	0	1	0	1	1	0	1
(f)			<59	5	4	2	3	4	11	7	18	11	7
			>59	0	0	0	0	1	0	1	1	0	1

(a) All values are arithmetic means, except FC and Ent. (geometric means) and metals (values are from one or more sampling occasions)

(b) CV = Coefficient of Variation = Standard Deviation/Mean

(c) Summer means (late May - September)

(d) Winter means (October - March)

(e) Four-day average concentration for hardness = 100 mg/L as CaCO_3 .

(f) Four-day average concentration for hardness = 50 mg/L as CaCO_3 .

the seven were open-water wetlands. The two highest summer mean values occurred in ELS61 (71.1 $\mu\text{g/L}$) and HC13 (65.5 $\mu\text{g/L}$), both of which have large open-water pooled areas. High algal productivity in ELS61 is likely due to elevated phosphorus levels resulting from new construction and a small cattle farm in the watershed, and internal loading in the wetland itself. Runoff from logging activities in the watershed and low flushing rates in the wetland during the summer probably contribute to the high values seen in HC13. The five other wetlands exceeding the criterion had mean values between 10 and 20 $\mu\text{g/L}$.

Winter mean TP values of 20 and 50 $\mu\text{g/L}$ are considered indicative of eutrophic and hyper-eutrophic conditions, respectively, in freshwater lakes (Welch 1980). When considering these values for purposes of comparing wetland TP levels, however, it is important to note that wetlands are shallower and have much faster flushing rates than most lakes. Winter mean TP values exceeded 20 and 50 $\mu\text{g/L}$ in 16 and eight, respectively, of the 19 wetlands. There were no obvious trends of higher TP values based on the five categories, treatment status or hydrological conditions. The two highest winter mean TP values occurred in AL3 (163 $\mu\text{g/L}$) and ELS61 (155 $\mu\text{g/L}$). These two wetlands are the only wetlands in the study that have agricultural land uses within their watersheds. All other wetlands had winter mean TP values of 100 $\mu\text{g/L}$ or less.

The FC standard for class B surface waters (GM = 200 org/100mL) was exceeded in three of the 19 wetlands. GM values for B3I, FC1 and ELW1 were 328, 230, and 217 org/100mL, respectively. The class A standard (GM = 100 org/100mL) was exceeded in MGR36 (GM = 125 org/100mL). All other wetlands were below the most stringent state standard (class AA: GM = 50 org/100mL). All four of the above noted wetlands are flow-through systems, but they have different levels of watershed development. The two highest GM values, however, occurred in those wetlands with the most highly developed watersheds (B3I and FC1).

In 1986, EPA proposed a freshwater criterion for enterococci of 33 org/100mL (Federal Register 1986). The GM for enterococci for seven of the 19 wetlands exceeded 33 org/100mL. The same four wetlands noted above for FC (B3I, FC1, ELW1 and MGR36) exceeded 100 org/100mL, while all other wetlands were below 50 org/100mL. Six of the seven wetlands exceeding the criterion are flow-through systems. As noted in Section 3.2.4, the quiescent nature of open-water systems, which allows sediment particles and associated bacteria to settle out, may influence significantly the lower bacterial values seen in open-water systems.

The entries in Table 9 for metals were not determined on the basis of mean values, because a majority of samples contained metals below detectable levels (Section 3.2.5). Therefore, entries were made if one or more detectable values exceeded the criteria. In the following discussion, the criteria are based on a hardness of 100 mg/L as CaCO_3 . Tables 8 and 9 summarize the

results discussed below. On one of the seven sampling occasions for metals, the criterion for Cd ($1.1 \mu\text{g/L}$) was exceeded at KE, the criterion for Cu ($12 \mu\text{g/L}$) was exceeded at AL3 and LPS9, and the criterion for Zn ($110 \mu\text{g/L}$) was exceeded at JC28. For Pb, however, the criterion was exceeded everytime detectable levels were found. The Pb criterion was exceeded on at least one occasion at 11 of the 19 wetlands. Detectable levels of Pb were found on two or more occasions at B3I, ELS61, JC28, LPS9, SC4 and SR24. There were no obvious trends for detectable Pb levels based on the five categories, treatment status or hydrological conditions.

4. CONCLUSIONS

The quantity and quality of stormwater entering many palustrine wetlands in the Puget Sound region has changed as a result of rapid development in urbanizing areas. These changes may affect the functions and values of wetlands by impacting soils, plants and animal communities. The purpose of this report has been to characterize the hydrology and water quality of palustrine wetlands affected by urban stormwater, in comparison to unaffected systems. This information, then, may help to explain observed changes in wetland soils, plants and animals over time. Additionally, if observed effects of stormwater on wetlands can be documented, it may be possible to mitigate these effects through watershed controls or pretreatment efforts.

The hydrology of the wetlands included in this study was highly variable. The range of maximum water level fluctuations for the 19 wetlands was large (0.62 to 4.28 feet), but there was no obvious association with the type of hydrologic system (open water versus flow-through) or outlet conditions. It is hypothesized that forthcoming information on wetland to watershed ratios and extent of watershed development will help to explain these differences. Plant and animal communities likely will be affected more by significant fluctuations in water level than by pollutants at the levels generally found in runoff from urbanizing areas.

The control/highly urbanized (CH) and treatment/moderately urbanized (TM) wetlands exhibited the most degraded water quality conditions. In particular, the higher values for conductivity, TSS, FC and enterococci of these two wetland categories reflect degraded water quality conditions. There were surprisingly few significant differences between control and treatment wetlands; however, those variables that were different (SRP, conductivity and $\text{NO}_3 + \text{NO}_2 - \text{N}$) reflect higher loadings of nutrients and dissolved salts. These differences will likely increase as development continues and analyses are performed on variable changes, rather than baseline values.

Overall, the water quality of the wetlands was characteristic of freshwater systems receiving stormwater inputs. The values

observed were similar to those found in freshwater lakes and streams in the region. Since water is transient, its greatest effect probably results from accumulation of pollutants in the sediments due to physical settling and chemical reactions. High fluctuations in water levels likely pose more significant problems to wetland functions because of potential effects on plant succession, habitat and breeding conditions.

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